# Two mechanisms of positive boundary layer cloud feedback in large-eddy simulations

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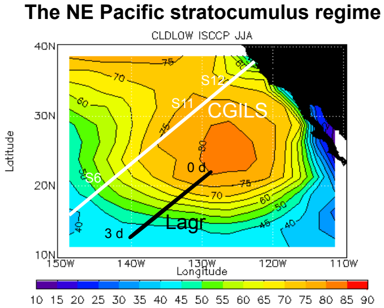
- Large-eddy simulations (LES) of subtropical cloud-topped boundary layers are run with control and perturbed forcings that isolate the cloud response to different aspects of greenhouse warming.
- Radiative and thermodynamic and mechanisms for cloud reduction are found. These can partly compensated by lower tropospheric stability increases.
- 'Entrainment Liquid-Flux' (ELF) adjustment is proposed to explain thermodynamically driven cloud thinning in stratocumulus, shallow cumulus and intermediate regimes.

## The NE Pacific stratocumulus regime

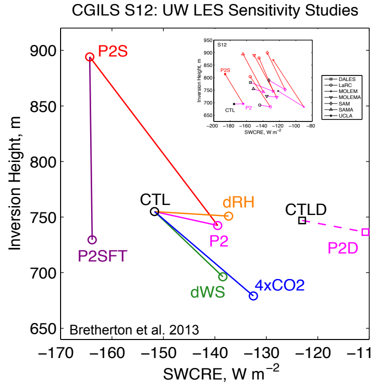



## CGILS Eulerian simulations

CGILS: **C**FMIP-**G**ASS **I**ntercomparison of [cloud feedbacks in] **L**ES and **S**CMs

Eulerian 10-20 day steadily-forced simulations at S12 (well mixed Sc), S11 (Cu under Sc) and S6 (shallow Cu) with current JJA forcings and various idealized climate changes.

CGILS S12: UW LES Sensitivity Studies




8-10 day means from:
CTL: Control S12 forcings
4CO2: 4x$CO_2$, no SST or atm warming
dRH: 5% free-trop relative humidity decrease
dWS: 10% surface wind speed reduction
P2: 4 K SST and atm warming, const. RH
P2S: P2 with 10% subsidence decrease
P2SFT: P2S with no SST or MBL warming
'D' runs use diurnally-varying insolation.

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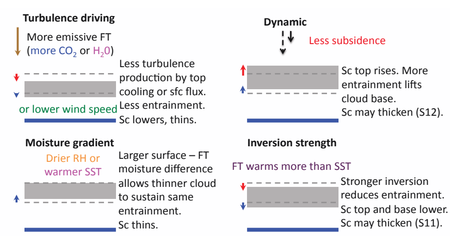
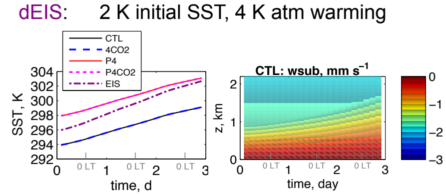
## CGILS-inferred cloud response mechanisms

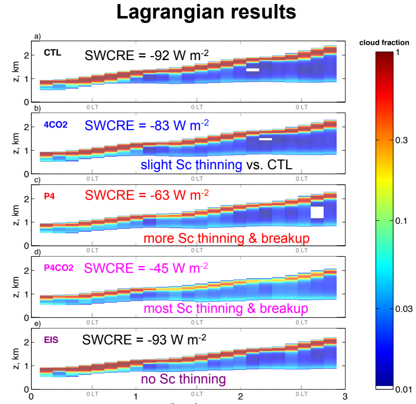



## Lagrangian simulations

- Sandu and Stevens (2011) composite Sc-Cu transition case adopted for GASS intercomparison used as control (CTL) case.
- PBL warming/deepening forced by 1.5 K day$^{-1}$ SST rise and very weak subsidence.
- Incomplete transition; Cu-under-Sc throughout
- We added several climate perturbations:
  - 4CO2: 4x$CO_2$, no SST or atm warming
  - P4: 4 K SST and atm warming, const. RH
  - P4CO2: Both of the above
  - dEIS: 2 K initial SST, 4 K atm warming

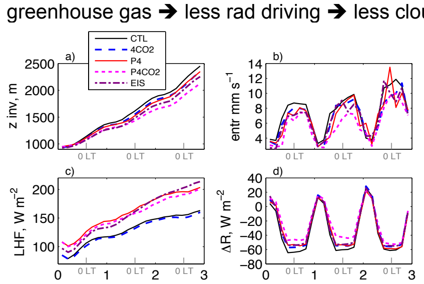



## Lagrangian results

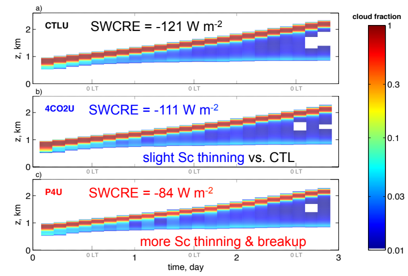



- Warmer MBL = more latent heat flux
- Less MBL rad cooling ΔR = less entrainment and less cloud unless compensated by larger EIS.

**Radiative cloud response**: More overlying greenhouse gas ➔ less rad driving ➔ less cloud



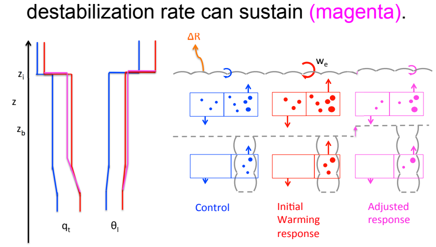

## Similar response with uniform insolation




- 4CO2 and P4 have same ΔR, inversion strength, entrainment rate for first 36 hrs, but P4 has thinner cloud, isolating the thermodynamic cloud response to warming.

## Entrainment Liquid-Flux (ELF) adjustment and thermodynamic cloud thinning

Consider a given cloud layer from a control climate (blue) that is instantaneously transplanted to a climate with the same RH profile but uniformly warmed $\theta_l$ (red). The warming enhances updraft-downdraft differences in humidity, hence in-cloud liquid water and temperature. Hence, the cloud layer produce a burst of more liquid flux, more buoyancy flux, stronger turbulence, and more entrainment. The entrainment exerts a drying feedback that quickly reduces cloud until liquid flux and entrainment adjust to levels that the fixed radiative destabilization rate can sustain (magenta).




- ELF adjustment can reduce both Sc and cumulus boundary-layer cloud in a warmer climate. For pure Cu, it reduces to a mechanism proposed by Rieck et al. (2012); for well-mixed Sc, to one proposed by Bretherton et al. (2013). Cu are less sensitive than Sc to an entrainment change, so for pure Cu, the adjusted state maintains more entrainment and a deeper boundary layer as well as less cloud cover.

**References**:

CGILS papers
- Zhang et at 2012 JAMES
- Blossey et al 2013 JAMES
- Bretherton et al 2013 JAMES

Cu cloud feedbacks
- Rieck et al 2012 JAS

Lagrangian cloud feedbacks
- Bretherton and Blossey, JAMES, submitted July 2013